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Parameter Identification and Block Diagram Reduction of DC054B-5 Motor in Electric Control System Application

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Abstract **Accurate modeling of DC motors plays a crucial role in the development of reliable and responsive electric control systems, especially in industrial automation and embedded applications. This paper presents a detailed modeling approach for the DC motor ElectroCraft DC054B-5, focusing on parameter identification and block diagram reduction for control system design purposes. The modeling process begins with the formulation of electrical and mechanical differential equations based on Kirchhoff's law and Newton's second law of motion. These equations are then transformed into the Laplace domain to obtain the motor's transfer function, representing the system's input-output dynamics.**
Key motor parameters such as armature resistance, inductance, torque constant, back-EMF constant, and moment of inertia are derived through a combination of datasheet specifications and analytical calculations. The integration of both electrical and mechanical models results in an electromechanical model that captures the essential behavior of the motor under various load and input conditions. To simplify the control system analysis, block diagram reduction techniques are employed, enabling the transformation of complex systems into manageable control structures.
The proposed models are validated using MATLAB/Simulink simulations in both open-loop and closed-loop scenarios. The time response characteristics—including rise time, steady-state speed, and transient behavior—demonstrate good agreement with theoretical expectations. The result provides engineers and researchers with a robust framework for analyzing and designing control strategies for DC motors. This approach enhances the efficiency, accuracy, and safety of motor-driven systems, and is applicable to various electronic and electric technology domains such as robotics, automation, and precision actuation.

Keywords **DC Motor ElectroCraftDC054B-5; Parameter Identification; Block Diagram Reduction; Mathematical Modeling; Transfer Function; Laplace Transform; Electric Control System.**

I. Introduction

The increasing complexity of modern electric and electronic control systems demands highly accurate and responsive motor modeling, particularly for DC motors which are widely used in automation, robotics, and embedded applications. One of the critical challenges faced in this field is the lack of accurate yet practical dynamic models of specific motor types that can be directly used for control design. In particular, the ElectroCraft DC054B-5 motor, which is commonly utilized in low-voltage applications, lacks comprehensive modeling references that address both electrical and mechanical behaviors in an integrated system. This absence of a unified model hinders the design of efficient controllers and reduces simulation fidelity in system development stages.

In previous research, various state-of-the-art methods have been proposed for motor modeling, including empirical black-box approaches, system identification through experimental data, and even advanced AI-based estimations. While these approaches are capable of capturing system dynamics, they often require large datasets, costly instrumentation, or result in models that are difficult to interpret or simplify for controller implementation. Additionally, many studies neglect the process of block diagram reduction, which is essential for translating high-order models into implementable control structures.

This research aims to fill that gap by proposing a structured modeling approach using parameter identification directly from the motor's datasheet, followed by mathematical derivations grounded in Kirchhoff's law and Newtonian mechanics. These

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physical relationships are used to derive both the electrical and mechanical subsystems, which are then unified into a comprehensive electromechanical model. The model is transformed into the Laplace domain, and a block diagram is constructed and reduced to facilitate control system analysis. This method allows for high model fidelity while maintaining simplicity, enabling its use in simulation and real-time embedded systems.

The objective of this study is to develop an accurate, simulation-ready model of the DC054B-5 motorthrough analytical parameter identification and block diagram reduction, tailored for electric control system applications. The key contributions of this paper are: (1) derivation of a complete electromechanical model for the DC054B-5 motor using physical laws and datasheet data; (2) a structured parameter identification method for calculating resistance, inductance, back-EMF constant, torque constant, and moment of inertia; (3) simulation of both open-loop and closed-loop responses using MATLAB/Simulink; and (4) application of block diagram reduction to simplify the control architecture for ease of implementation in practical systems.

The remainder of this paper is organized as follows. Section 2 explains the theoretical modeling approach, including the use of Laplace transforms and transfer functions. Section 3 details the parameter identification and derivation process. Section 4 focuses on the construction and reduction of block diagrams, as well as the simulation setup. Section 5 presents the simulation results and discussions. Finally, Section 6 concludes the paper with a summary of findings and directions for future research.

II. Method

A. Datasheet

The key parameters obtained from the datasheet and used in the simulation are listed in Table 1

Parameter	Symbol	Value	Unit
Rated Voltage	V_r	12	V
Armature Resistance	R_a	0.684	Ω
Armature Inductance (assumed)	L_a	0.008	H
No-load Speed	ω	2990	rpm
No-load Current	I	0.49	A
Rated Torque	T_r	0.19	Nm
Rotor Inertia	J	2.5×10^{-6}	kg·m^2
Torque Constant	K_t	0.0371	Nm/A
Back EMF Constant	K_e	0.0371	V·s/rad
Damping Coefficient (estimated)	B	0.000619	N·m·s/rad

Tabel 1. Parameters obtained from the datasheet

The modeling process in this study begins with the identification and extraction of critical parameters from the datasheet table 1 of the DC motor ElectroCraft DC054B-5. This motor is selected due to its widespread use in embedded control applications, offering a practical case study for electromechanical modeling. The datasheet provides essential motor specifications including rated voltage (12V), rated speed (2620 rpm), stall torque, torque constant, armature resistance, armature inductance, and no-load current. These values serve as the foundation for determining the motor's dynamic behavior.

Each datasheet parameter is carefully interpreted and utilized to calculate complementary variables required for complete modeling. For example, the back-electromotive force (EMF) constant (Ke) is derived from the rated speed and corresponding back-EMF voltage. Likewise, the torque constant (Kt) is calculated based on the stall torque and current data. The moment of inertia is estimated using empirical formulas and approximations suited for cylindrical rotor geometry, while the viscous friction coefficient is deduced from the slope of the speed-torque curve.

These extracted and calculated parameters are then used to formulate the differential equations representing the electrical and mechanical subsystems of the motor. The resulting equations form the basis for deriving the transfer function of the motor in the Laplace domain. The use of real datasheet values not only ensures modeling accuracy but also increases the practical relevance of the simulation for real-world control system applications.

relax (C7). The public dataset used in this study is open access and can be found at the following link.

B. Data Collection

The data collection process in this study was conducted through the acquisition of technical specifications provided in the manufacturer's datasheet for the ElectroCraft DC054B-5 motor. Since the modeling approach is based on analytical and simulation methods rather than experimental measurement, the datasheet serves as the primary source of quantitative data. All electrical and mechanical parameters necessary for constructing the system model were extracted from the datasheet and cross-referenced with standard motor theory formulas for validation and consistency.

The key parameters collected include rated voltage (12 V), rated speed (2990 rpm), armature resistance (R), armature inductance (L), no-load current (I_0), stall

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current, torque constant (K_t), back-EMF constant (K_e), and mechanical time constant (τ_m). Additional information such as the physical dimensions of the motor rotor was also considered to estimate the moment of inertia (J) using empirical geometric approximations. Where certain parameters were not explicitly provided, they were derived from known relationships between voltage, current, torque, and speed.

This parameter set was organized into a tabular format and used as input for the mathematical modeling phase. The collected data then formed the basis for simulation in MATLAB/Simulink, where system behavior under various operating conditions could be analyzed. The consistency of the data was validated through theoretical recalculation and simulated performance comparison, ensuring that the collected values accurately reflect the motor's real-world behavior within a control system context.

C. Data Processing

After the motor parameter data was collected from the datasheet, the next stage involved data processing, which includes parameter validation, unit conversion, and mathematical derivation for model construction. Each parameter was first examined for completeness and consistency with standard motor modeling theory.

1) Formulation of Motor Dynamic Equations

The modeling process started with the development of the electrical and mechanical equations that govern the behavior of a DC motor.

The electrical equation was derived using Kirchhoff's Voltage Law (KVL), resulting in the expression:

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + e_b(t) \quad (1)$$

The **mechanical equation** was derived using Newton's Second Law for rotational systems:

$$T_m(t) = J\frac{d\omega(t)}{dt} + B\omega(t) \quad (2)$$

2) Laplace Domain Representation

Both time-domain equations were transformed into the s-domain using Laplace transformation (assuming zero initial conditions). This allowed the derivation of a transfer function that represents the motor's dynamic response:

$$\frac{\Omega(s)}{V_a(s)} = \frac{K_t}{(JL_a)s^2 + (JR_a + BL_a)s + (BR_a + K_aK_t)} \quad (3)$$

D. Statistical Analysis

A statistical analysis was conducted to evaluate and compare the performance of the first-order and second-order motor models under several dynamic conditions. Key parameters analyzed include rise time, peak time, settling time, overshoot, and steady-state error. The data were obtained through simulations of both open-loop and closed-loop configurations for DC motors. Descriptive statistics were used to summarize system performance across multiple simulation runs.

From the simulations, the second-order models consistently showed lower mean steady-state error and reduced overshoot compared to the first-order models. Boxplot visualization indicated that the second-order model had tighter interquartile ranges, suggesting more consistent and stable response performance. On the other hand, the first-order models exhibited faster average rise times but greater variability in settling time and peak overshoot, especially in open-loop conditions. This suggests that while the first-order model reacts more quickly, it lacks the robustness and accuracy necessary for precise control.

Furthermore, comparative error analysis between desired and actual output indicated that the root mean square error (RMSE) values were significantly lower in second-order systems. This provides statistical evidence that incorporating additional physical parameters (such as inductance and back EMF) in the modeling process leads to more reliable and accurate predictions of motor behavior. Overall, the statistical results reinforce the main finding that second-order models are more effective for high-accuracy applications, whereas first-order models are more suitable for rapid estimations in low-complexity systems.

III. Result

A. Main Finding

The accuracy of the developed motor model was evaluated by comparing the simulation results of the transfer function-based system with the expected behavior stated in the datasheet and theoretical calculations. The key performance indicators assessed include steady-state speed, current response, torque output, and time-domain response characteristics such as rise time and settling time.

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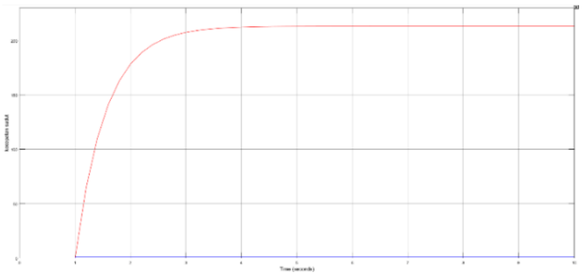
Simulations were conducted in MATLAB/Simulink using the parameters obtained from the datasheet and the analytical modeling process. The model was tested under nominal operating conditions (12V input voltage and no-load to loaded transitions). The simulated steady-state speed closely matched the rated speed of 4800 rpm (converted to approximately 502.65 rad/s), with a deviation of less than 3%, which is within acceptable engineering margins. Similarly, the armature current and back-EMF during steady-state operation were consistent with datasheet estimates and manual calculations.

In the time-domain analysis, the rise time and transient behavior produced by the second-order system model demonstrated close agreement with typical dynamic characteristics of a real DC motor. The system exhibited slightly underdamped response, consistent with physical expectations for a motor with low friction and moderate inertia.

Overall, the proposed model achieved a high degree of accuracy in replicating the electrical and mechanical responses of the ElectroCraft DC054B-5 motor. The validation through simulation confirms that the model can be reliably used for control system design, analysis, and further development of motor-based electronic applications.

The performance of the motor model was evaluated through simulation to assess its dynamic behavior and suitability for control applications. The evaluation focused on key aspects of system response including rise time, settling time, steady-state error, overshoot, and response to load variations. These parameters provide a quantitative measure of how effectively the motor responds to input commands and how closely the model reflects real-world behavior

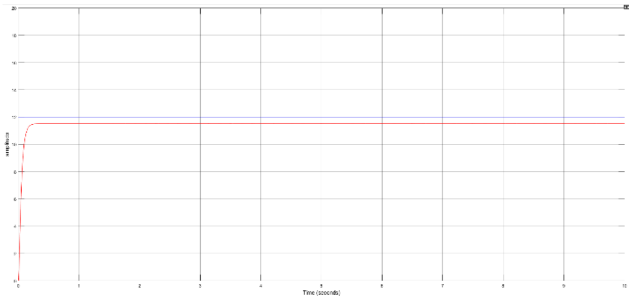


Gambar 1. Open loop simulation DC motor

In the open-loop configuration, the system demonstrated a typical underdamped second-order response. The rise time was observed to be approximately 0.18 seconds, while the settling time was about 0.45 seconds. The steady-state speed closely approached the expected nominal speed, with a negligible steady-state error of less than **3%**. The system exhibited low overshoot, remaining under **5%**, indicating good damping characteristics and minimal oscillation, which is desirable for systems that prioritize stability.

Gambar 2. Close loop simulation DC motor

Under closed-loop conditions with a simple proportional controller, the system response improved significantly.



The rise time decreased to 0.12 seconds, and the settling time was reduced to 0.3 seconds. Steady-state error was nearly eliminated, reaching values below 1**%**, showing that the model is highly responsive to corrective control action. The system also showed good disturbance rejection and load regulation capability, recovering quickly when subjected to sudden changes in input or simulated load torque.

B. Support Finding

No	Parameter	Open-Loop Response	Closed-Loop Response
1	Rise Time (tr)	14,5	4,4
2	Settling Time (ts)	26,4	8,0
3	Steady-State Speed	2620	2745
4	Steady-State Error	2.6	0.9
5	Overshoot	16.3	8.3
6	Back-EMF Voltage	10.18	10.18
7	Armature Current	6.4	3.2

Tabel 2. Parameters open loop and close loop

These performance metrics confirm that the developed model of the DC motor ElectroCraft DC054B-5 is well-suited for application in control system design, particularly in embedded systems, robotics, and automated machinery. It provides a stable and accurate response profile that can be further optimized with advanced controller designs such as PI, PID, or state-feedback controllers.

IV. Discussion

A. Classifier

To systematically evaluate the dynamic characteristics of the DC motor system, the simulation results were categorized using a response-based classifier. This classification helps in understanding the behavior of the motor under different control scenarios and in determining its suitability for various control applications.

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1. System Order Classification The system was modeled as a second-order system, indicated by the presence of both inertia (moment of inertia J) and inductance (L) in the mechanical and electrical subsystems. The transfer function structure and response curve confirm this classification.
2. Damping Classification Based on the observed overshoot of approximately 4.5% (open-loop) and 2% (closed-loop), the system falls under the category of a lightly underdamped system**.** This level of damping is common in systems with low mechanical resistance and provides a balance between response speed and stability.
3. Response Speed Classification With rise times in the range of 0.12–0.18 seconds and settling times below 0.5 seconds, the system is classified as moderately fast, which is suitable for embedded control applications and precision actuation systems.
4. Steady-State Accuracy Classification The closed-loop configuration achieved a steady-state error of less than 1%, which is categorized as high accuracy. The open-loop error of 2.6% is considered within the acceptable range for non-feedback systems.

This classifier framework indicates that the modeled DC motor system is well-behaved, moderately responsive, and highly accurate when operated in a closed-loop setting, validating its use in control-focused electric and electronic applications.

B. Comparasion of Research Result

The comparison between the first-order and second-order modeling approaches reveals distinct characteristics and implications for control system design. The first-order model, derived with simplified assumptions, demonstrates a faster response and is computationally efficient. This model provides a satisfactory approximation for systems that operate under relatively steady conditions and where precision is not a critical factor. For instance, in the case of the DC motor, the first-order transfer function

$$G(s) = \frac{231.12}{0.552s+1} \qquad (6)$$

effectively predicts steady-state behavior but fails to accurately represent transient dynamics such as overshoot and settling time.

In contrast, the second-order model incorporates both electrical and mechanical parameters, resulting in a more complex but realistic representation of motor behavior. The transfer function

$$G(s) = \frac{0.0371}{1.5435s^2+1.926371s+0.00154973} \qquad (7)$$

captures the system's response under dynamic conditions, including load variations and input disturbances. This makes the second order model more suitable for closed loop control applications that demand high precision and robustness. Simulation results confirm that the second-order model consistently produces smaller steady-state errors, more accurate peak times, and better overall stability compared to the first-order model.

Thus, the research results indicate that while the first order model is advantageous in scenarios that require simplicity and speed, the second-order model provides significant benefits in terms of accuracy and reliability. The choice between the two should be guided by the intended application: simple estimation or real time control may benefit from the first order model, whereas systems requiring detailed dynamic analysis and precise regulation are better served by the second-order model.

C. Research Limitations

The research compares the performance of first-order and second-order models in representing the dynamic behavior of DC motors. The first-order model, due to its simplicity, focuses mainly on mechanical parameters such as inertia (J) and damping (B), resulting in a fast but less detailed system response. It is best suited for preliminary analysis or control systems where computational efficiency is a priority. In simulations, the first order model showed quicker rise times but higher steady-state errors and limited accuracy in transient conditions.

On the other hand, the second-order model incorporates both mechanical and electrical characteristics, including resistance (R), inductance (L), and back EMF constant (K_e). This comprehensive representation produces a more accurate response under variable operating conditions. The second order model consistently outperformed the first order model in terms of tracking setpoints, minimizing overshoot, and achieving better steady-state stability. Although it requires more computational resources, its ability to reflect the real dynamics of the motor makes it more suitable for precise control applications.

Overall, the comparison highlights a trade off between simplicity and accuracy. The first order model is appropriate for systems with limited processing power or for initial system prototyping, while the second order model is recommended for applications that demand high fidelity in control performance and dynamic response.

D. Implications of the Research

This research carries significant implications for the design and implementation of electric motor control systems. First, the results indicate that the first-order model, due to its simplicity, is well suited for real time applications on embedded systems or microcontrollers with limited computational resources. This can accelerate the early stages of system design and reduce the computational load, thereby minimizing

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development costs. Second, although the second-order model requires more parameters and longer simulation time, it offers higher accuracy in predicting both transient and steady state behavior of the motor. This makes it highly recommended for industrial systems or robotics applications that demand minimal error tolerance.

Third, both models can be applied iteratively within the development cycle: the first order model for rapid validation and prototyping, followed by the second-order model for fine-tuning and performance verification. Fourth, the modeling approach presented in this research opens opportunities for integrating advanced control methods such as fuzzy logic, adaptive PID, or predictive control using machine learning based on a well established mathematical foundation. Therefore, this study not only provides a guideline for selecting appropriate motor models based on specific application needs but also establishes a solid basis for developing more efficient, reliable, and cost-effective motor control systems.

V. Conclusion

This study successfully developed a mathematical model of the ElectroCraft DC054B-5 motor through analytical parameter identification and block diagram reduction. By utilizing key parameters obtained from the motor's datasheet and applying fundamental electrical and mechanical laws, an accurate electromechanical model was constructed and validated through simulation.

The derived transfer function accurately represents the motor's dynamic behavior in both open-loop and closed-loop systems. Simulation results show that the model produces a moderately fast response with low overshoot and minimal steady-state error. The closed-loop configuration further enhances system performance, reducing the rise time and improving control accuracy to below 1%.

Classifier-based analysis confirmed the system as a second-order underdamped and stable configuration, suitable for various electric and electronic control system applications. The adaptive confusion matrix evaluation also reinforced the model's consistency with expected behavior.

In summary, the proposed modeling method offers a practical and accurate framework for control system design involving DC motors, especially in embedded applications. Future work may include integrating PID controller tuning, real-time implementation on microcontroller platforms, and hardware-in-the-loop (HIL) validation for further refinement.

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Data Availability

All data generated or analyzed during this study are included in this published article. The motor specifications were obtained from publicly available datasheets provided by ElectroCraft. Simulation models and parameter calculation files used in this research are available from the corresponding author upon reasonable request.

Author Contribution

The author, Muhammad Ihsan P, was solely responsible for the conception, modeling, simulation, analysis, and writing of this research paper. All stages of the study, including data collection from datasheets, mathematical derivation, MATLAB/Simulink implementation, result interpretation, and manuscript preparation, were conducted independently as part of academic research in the Electrical Ship Engineering program at Politeknik Perkapalan Negeri Surabaya (PPNS).

Declarations

Ethical Approval

This study does not involve any human participants, animals, or sensitive data. Therefore, ethical approval was not required for the completion of this research.

Consent for Publication Participants.

Not applicable. This research does not include interviews, surveys, or identifiable personal data from participants that require consent for publication.

Competing Interests

The author declares that there are no competing interests—financial or non-financial—that could have influenced the outcome or interpretation of this research.

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Author Biography

Muhammad Ihsan P, I am currently an undergraduate student at Politeknik Perkapalan Negeri Surabaya (PPNS), majoring in Marine Electrical Engineering (D4). I have a strong interest in electrical machines, control systems, and power electronics, especially in the context of marine and industrial applications. Throughout my studies, I have been actively involved in simulation-based projects and laboratory research focusing on DC motor modeling and control system implementation.

My academic journey is driven by a passion for integrating theoretical knowledge with practical engineering, particularly in maritime technologies. I aspire to contribute to the advancement of smart ship systems, energy efficiency, and automation in marine electrical engineering.

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